Reference 2

January 14, 1997

MEMORANDUM FOR: Randy Brunts (DELCO):
Chairman, EIA/CEMA DAR Subcommittee

FROM: Don Messer (US Information Agency): Don Messer
Digital System Proponent

Message sent via Fax to Mr. Brunts; courtesy copies also sent via Fax to:

Ralph Justus (EIA/CEMA)
Charles Morgan (Susquehanna Radio)
Arvydas Vaisnys (JPL)
Bernee Strom (USA Digital)
Ed Chen (Lucent Technologies)
Clint Pinkham (Thomson Consumer Electronics)
David Layer (NAB/Sci. & Techno.)

SUBJECT: Reaction to the 1/97 Draft Report entitled "Technical Evaluations of Digital Audio Radio Systems Performance"

Yesterday afternoon I received a copy via fax of the 12 page draft report cited under SUBJECT from Mr. Vaisnys, who attended the DAR Subcommittee meeting in Las Vegas last Saturday as our representative. He has not yet sent me the appendices mentioned in the draft report. None of the comments I make in this memorandum depend on a review of the appendix material.

Before beginning my specific comments on the report, you should know that I only received an announcement of the Las Vegas meeting a few days before it took place. That is not much time.

I first thought that the draft report was an add-on to the excellent field test summary that I received last week. However, after scanning it, it is clear that it is meant to be an evaluation report based on all the testing done, laboratory and field. It is largely because of this scope that I have decided to write this memorandum to you as soon as possible.

1. What happened to the evaluation report procedures we had agreed to?

Mr. Vaisnys told me that the draft evaluation report was handed out at the Las Vegas meeting last Saturday toward the end of the meeting. He said it was not discussed. He also said that comments on it are due by the end of February.

If this is to be the procedure, it is quite different from what we agreed to in more than one DAR subcommittee meeting. My recollection is that a working group was to be set up. I asked to be a member of that group. This should have been duly noted, at least from the September 25, 1996 meeting. At that time it was noted that a chairman still had to be found.

I have not received any notice since that time about the composition of the working group or its work schedule. It never occurred to me that shortly after the release of the Field Test Data Presentation we would be presented with a draft of the evaluation report from an unrecorded author(s). In short, what happened to the working group? And if it did meet or do its work by correspondence, why was I not invited to participate?

Keeping in mind all the diversity of opinion during the entire working period of the DAR subcommittee, I would have thought more care and attention would have been paid to the production of even a draft of the evaluation report than what I have before me: a quick, superficial rendering of alleged analysis.

2. The draft technical evaluation report is shallow, woefully biased, and as a result reflects poorly on the EIA/CEMA.

Condensing the enormous set of tests that were done in the laboratory and in the field into a short report is not a simple matter. However, the author(s) of the draft report could have tried to highlight all the important matters, not be selective to present a viewpoint that can readily be challenged. I wouldn't be so concerned if the subcommittee were performing promotional work for a product. But the subcommittee is supposed to represent the results of the tests in an unbiased and fair manner, keeping in mind that the public, manufacturers, broadcasters and the FCC will need to be able to scrutinize the major elements of the work in order to make their own decisions.

Because of the hodge-podge variety of systems tested and the radio frequencies chosen, the DAR evaluation is not simply one of choosing from a narrowly defined set of alternatives. As things turned out, we had to deal with radio frequencies from 1 to 2000 MHz, with satellite and terrestrial delivery, and with consequent regulatory and operational differences that could be dominant in any final selections of what the U.S. should do with respect to the introduction of digital radio services.

Therefore, it is terribly inappropriate to say, without any attempt to display the subtleties, that system x is better than all other systems,.... A few examples of distortion and misstatement are given in the following few paragraphs.

a. Unimpaired audio quality:

After all the concerns were expressed since August 1995, once again we see the ranking displayed as if there were important differences in inherent quality among the systems tested. In point of fact, these differences were minimal for those systems with source encoder bit rates 160 kbps or higher, with the exception of one of the Eureka 147 systems. To blow this "glockenspiel-type" distinction way out of proportion, particularly for mobile reception, which was the hallmark of the tests, is absurd.

b. Impaired audio quality:

For example, the draft report leaves out totally the fact that the VOA/JPL system consistently performed 3 dB or so better than Eureka 147 with noise impairments. This is a significant factor when considering signal robustness and required protection ratios.

The VOA/JPL system was categorized as exhibiting extremely poor performance under multipath conditions. As was explained many times during the course of the work, multipath effects are minimal from a satellite. The VOA/JPL system tested was not designed to counter multipath, nor were tests on it in the laboratory reported. As we have also mentioned many times, we had not completed our adaptive equalizer design to combat multipath for terrestrial booster application at the time designs were frozen for the lab. Therefore, the multipath comment is irrelevant. (Since then, we have our equalizer design working well, and are working on an HF system design with it as an inherent part of the design.)

c. Field test coverage results:

The draft report properly notes that the Table 2 summary does not show where geographically a system failed ... Then it goes on to show the display anyway, with another sort of ranking analysis. It then concludes with a somewhat tautological statement that coverage is what coverage gets.

Table 2, by the way, shows two interesting things: (1) that the satellite system did "better" than the other systems everywhere but on the downtown and the San Francisco perimeter routes, sometimes significantly "better"; (2) that the terrestrial systems did well on these two routes, whereas the satellite system did fairly in the perimeter route and poorly in the downtown route.

What is ~~so~~ "startling" about this? ("Startling" is used in the draft text with reference to blockage for satellite delivery.) We have noted over and over again that 7 watts from a geostationary satellite at a twenty-plus degree elevation angle at L-band or S-band will not overcome building blockages. Anyone following experiments done over the past several years by us and others should know this. Any conclusions re satellite delivery based on the EIA/CEMA field tests should highlight this phenomenon in a way that will assist people in understanding how to use satellite delivery, not to pan it out of hand. To wit, it is clear that satellite delivery at L-band and S-band will require terrestrial assistance in many urban environments. This is not so much a case of specific system design, but of propagation physics and the fact that 30 to 40 dB margins are not currently attainable with realistic communication satellites.

Additionally, for anyone who has visited the Mt. Beacon and San Bruno sites, it should be evident that any reasonably powered digital system at either VHF or L-band should be able to do well into cars and trucks on the downtown and perimeter routes. It remains for additional analyses to understand why the terrestrial systems did so poorly on the east, west and north routes.

3. No indoor tests of value--a severe deficiency.

I was a strong supporter of conducting indoor reception measurements. It is a pity that no useful data were obtained during the field tests.

If all the systems had been operating at VHF, this lack of data would not have been much of a problem. However, it is crucial to the evaluation of higher radio frequencies to get an understanding of what power levels will be needed to have fine reception indoors. Car and truck reception is not the only way people listen to radios, particularly if CD quality is one of the important criteria.

We had a fine opportunity to evaluate L-band terrestrial performance in a variety of indoor situations within an independent test program. The VOA/JPL in its own experiments have conducted tests under a variety of building conditions, mostly at satellite elevation angles. Obviously, signal absorption is a significant factor at these frequencies.

Since we do not have these kinds of important data for the higher frequencies, this lacuna and its consequences for overall radio system evaluation should be prominently noted in our evaluation report. No local radio station is going to get on a digital bandwagon for "outdoor" reception only.

To paraphrase one of the major objectives for the testing, particularly the field testing, the work should provide valuable information to compare all the digital systems with existing FM at VHF. My review of the voluminous test data indicates to me that we have yet to do this. My cursory review of the limited field testing does not convince me that any of the terrestrial systems will provide significantly better performance than current FM systems. There is nothing yet displayed that shows that coverage has been enhanced; for example, I have seen no parallel data that shows what an FM system's response would have been over the six long paths used. Without indoor testing of any system and without any IBOC testing, we may need to conclude that the jury is still out.

4. Recommendation: Set up the Data Evaluations Working Group, staff it with the appropriate people, including those who have been with the process for years, take enough time, and produce a report the EIA/CEMA can be proud of.

I believe any evaluation report from the DAR subcommittee that follows the lines and tone of the draft report I have reviewed will cause grief to the EIA/CEMA and, more importantly, be of little value to those who will ultimately be responsible for making decisions on the introduction of digital radio broadcasting in the U.S.

Therefore, I recommend that we institute the Data Evaluations Working Group. There is no rush. We should give this group adequate time to produce an evaluation report of real value, one the EIA/CEMA can hold up as worthy of the time, money and the efforts of many dedicated people who have tried to make this activity something of real use to the American public.

Finally, we will have to be forthright on identifying those things of importance that, for one reason or another, were not done in the test program.

Sincerely,

Don Messer

H. Donald Messer, Dr. Eng.
US Information Agency

Reference 3

National Association of BROADCASTERS

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September 20, 1996

Mr. Edward Y. Chen, Technical Manager
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Dr. Nikil S. Jayant, Head
Signal Processing Branch
AT&T/Lucent Technologies, Room 301
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Dear Messrs. Chen and Jayant:

We are encouraged to learn that USA Digital Radio and AT&T/Lucent/Amati are continuing development of IBOC DAB technologies. NAB recognizes the importance of this work and its potential benefit to the radio industry and the listening pubic. For that reason, NAB would like to offer its services to facilitate a fair and impartial IBOC testing program for all proponents as soon as the technology is appropriately developed.

As you know, NAB is a strong supporter of IBOC DAB over competing technologies. This is because IBOC, operating within existing allocated radio broadcast spectrum, has the greatest potential to preserve the infrastructure and viability of the United States radio industry while providing broadcasters and listeners with enhanced digital quality and ancillary data services.

DAB is a totally new concept for our industry that promises to take us into the era of competing digital services. We believe that will best be accomplished within existing assigned spectrum and encourage development of a digital radio system which maximizes that spectrum currently occupied by radio stations.

Our hope is that through this pioneering work of your respective companies, a DAB technology emerges that will benefit the general public, as well as all radio broadcasters. We look forward to working with you on the development of this technology and the fair testing of an IBOC DAB system for the next generation of radio service.

Kindest regards,

Eddie Fritts

REFERENCE 4

USA DIGITAL RADIO

October 9, 1996

USA DIGITAL RADIO CONTINUES TO DEVELOP IBOC DAB SOLUTION
WESTINGHOUSE WIRELESS SOLUTIONS LEADS DEVELOPMENT EFFORT

USA Digital Radio, the five-year old partnership between Westinghouse/CBS and Gannett Broadcasting, continues to develop and fine-tune its in-band, on-channel DAB solution and now has the resources and expertise of Westinghouse Wireless Solutions involved to lead that effort.

Bernee Strom, President of USADR, stated that the partnership recently completed extensive internal and external reviews of both the IBOC concept and of its own technology. "Third-party review has concurred with our conclusion that IBOC is quite viable and that all technical issues can be addressed to the satisfaction of broadcasters and regulators," she said.

The group's comprehensive technology development and implementation plan is being spearheaded by Westinghouse Wireless Solutions, the Baltimore-based team that has extensive experience in digital technology including, most recently, its development of the silicon carbide transistor for use in digital television.

Michael Jordan, Chairman and Chief Executive Officer of Westinghouse Electric Corporation, stated, "USADR's work over the past five years has yielded a great deal of information on the AM and FM bands and on working in-band DAB systems. While this work has also raised a series of difficult technical challenges, USADR is now proceeding with a revised technical design of its DAB system. We look forward to working with the NAB to insure that U.S. broadcasters are provided with an opportunity to implement DAB in an efficient and cost effective manner."

USA Digital Radio continues to work with the NAB to establish comprehensive, independent laboratory and field testing of the IBOC system.

* * *

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File F.5

IMPROVED IBOC DAB TECHNOLOGY FOR AM AND FM BROADCASTING

Reference 4

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A. J. Vigil, Ph.D., P.E.
USA Digital Radio, Linthicum, MD

ABSTRACT

Development of improved IBOC DAB systems for upgrade of AM and FM broadcasting is in process. Recent evaluation of the demonstrated AM and FM IBOC DAB systems has revealed specific weaknesses. Analysis of these weaknesses has exposed the underlying causes and solutions have been proposed to correct them. Identified weaknesses include interference between adjacent stations, propagation performance and interference of DAB, under some circumstances, to the host analog. Solutions include changes in spectral occupancy, power ratios and modulation format as well as the introduction of sideband diversity, time diversity and the formulation of a sensible transition plan that permits an all-DAB transmission format.

I. INTRODUCTION AND BACKGROUND

Digital Audio Broadcasting is a medium for providing digital quality audio, superior to existing analog broadcasting formats. The advantages of digital transmission for audio include better signal quality with less noise and wider dynamic range than with existing AM and FM radio. The goal of FM DAB is to provide virtual CD quality stereo audio and a 64 kbps ancillary data channel. The goal of AM DAB is to provide stereo audio with quality comparable to present analog FM quality and a 2.4 kbps ancillary data channel. The development of new high quality stereo codec algorithms indicates that virtual-CD stereo quality will soon be practical at rates as low as 96 kbps while stereo audio, startlingly superior in quality to existing AM audio, can be attained at 48 kbps. IBOC requires no new spectral allocations because each DAB signal is simultaneously transmitted within the same spectral mask of an existing allocation. IBOC DAB is designed, through power level and spectral occupancy, to be transparent to the analog radio listener. IBOC promotes economy of spectrum while enabling broadcasters to supply digital quality audio to their present base of listeners.

Recent evaluation of IBOC DAB systems proposed by *USADR* revealed various deficiencies in measured performance. In the Spring of 1996 *USADR* commissioned *Deskin Research Group* to conduct an independent technical study of IBOC DAB systems and to recommend modifications leading to the practical viability of IBOC DAB, if possible. Specific weaknesses were identified. Modifications were recommended towards a successful DAB system [1]. The conclusion of the study was that a successful FM IBOC DAB design is feasible, although challenging. Limited compromises in coverage area may be necessary in some cases as theoretical limits are approached. State-of-the-art digital audio compression techniques are crucial to the success of IBOC DAB.

This paper summarizes some weaknesses in previously proposed IBOC systems and begins to discuss improvements intended to both correct them, along with new techniques which will yield substantially more robust DAB systems.

The independent audit conducted by *Deskin Research Group* revealed various weaknesses in the previously proposed FM IBOC system. The primary areas for needed improvement include:

1. DAB interference to host FM signal.
2. Interference to DAB from the first adjacent FM signal.
3. Interference to the FM signal from first adjacent DAB.
4. Interference between DAB second adjacents.
5. Robustness of DAB in multipath fading environment.

II. INTERFERENCE ANALYSIS

USADR's demonstrated FM-1 DAB system employs a set of spread spectrum biorthogonal waveforms which are spectrally shaped to occupy passbands symmetrically placed on either side of the host FM signal. Figure 1 shows the location of the FM-1 DAB signal under the FM spectral mask. This figure shows only the positive half of the spectrum while the negative half is a mirror image. Notice that the vertical axis is labeled peak spectral density as opposed to a more conventional average power spectral density characterization. In this case, the total one-sided DAB signal power is actually only 18 dB below the FM carrier power while the peak spectral power ratio appears significantly greater. This is because the short-term FM spectrum is more "peaky" than the short-term DAB spectrum when both are observed in a 1 kHz bandwidth.

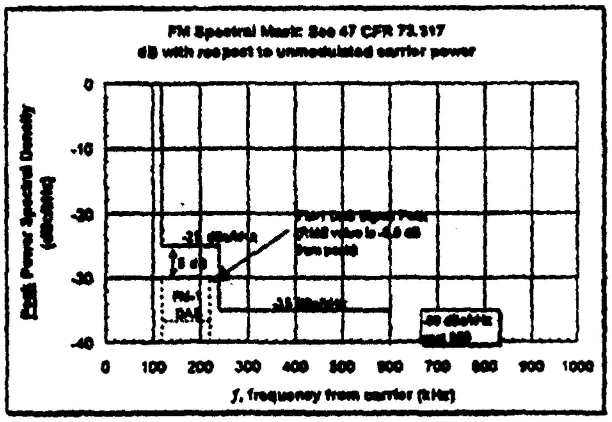

Figure 1. FCC Spectral Mask Requirements.

Figure 2 illustrates a typical FM signal spectrum with its DAB signal. Although the spectral shapes are not to scale, this figure presents the FM spectrum as a sinc-like lobe shape while the one-sided DAB spectrum is shown as rectangular. The DAB signal interference to its host is a function of both the placement or frequency offset of the DAB sidebands as well as their relative power levels. Recent testing revealed that a DAB average power level at -15 dB (-18 dB for each DAB sideband) relative to the average FM power results in some interference to a 92 kHz SCA signal (if present) as well as some interference to poorly designed receivers which have inadequate filtering near the third harmonic of the 38 kHz subcarrier. A recommendation to lower the DAB power will be quantified later in this paper.

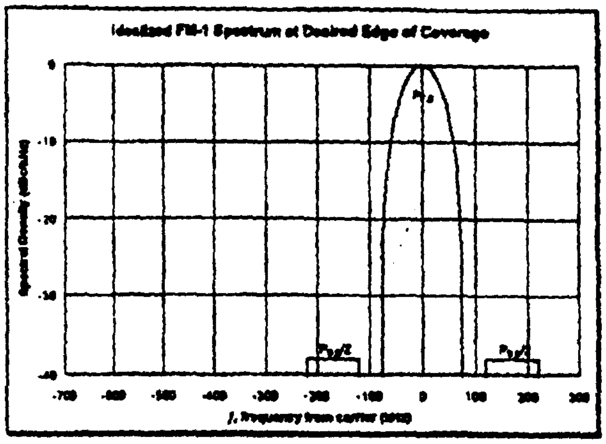

Figure 2. Example of FM Spectrum with DAB Sidebands.

The interference to and from the first adjacent channels placed ± 200 kHz away from the host signal can be derived from the relationship of the adjacent signals shown in the plot of Figure 3. FM stations are geographically placed such that the nominal received power of an undesired adjacent channel is at least 6 dB below the desired station's power at the edge of its coverage area. Then the D/U (desired to undesired power ratio in dB) is at least 6 dB. Knowledge of the ratio of each station's DAB signal power to its FM host permits assessment of first adjacent interference to DAB.

Similarly the interference of the first adjacent DAB to the host FM signal can be assessed from the relationship shown in Figure 4. In this example the host signal is shown at -200 kHz offset from the interferer.

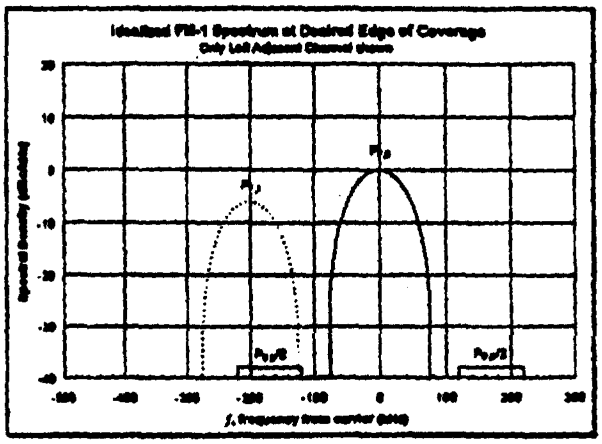

Figure 3. Interference to DAB from First Adjacent FM Signal.

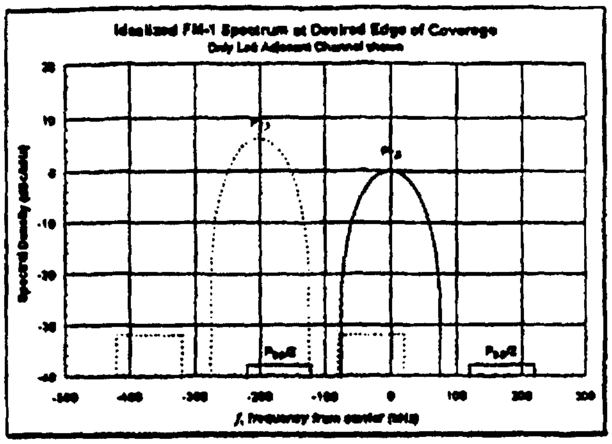

Figure 4. First Adjacent DAB Interference to Analog FM.

Figure 5 illustrates the obvious problem with the second adjacent DAB interference to the host DAB signal. At a station's edge of coverage, a second adjacent's nominal power can be up to 20 dB greater than the host nominal power. The overlapped portion of the host and second adjacent DAB spectra is the cause of the interference. This problem is easily remedied by pulling in the far edge of the DAB signal to within 200 kHz of its host carrier frequency to prevent spectral overlap.

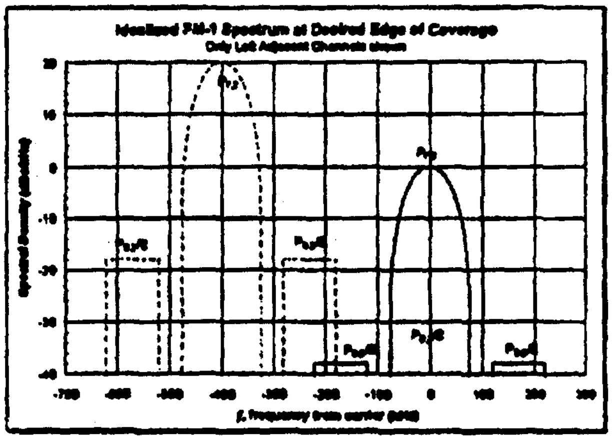

Figure 5. Second Adjacent DAB to DAB Interference

The effects of the various interference scenarios illustrated in Figures 2 through 5 were quantified through analysis and supported through simulation and testing. Analysis of the DAB to first adjacent interference at the edge of coverage showed that the total DAB signal should be set at about -21 to -25 dB relative to its FM host power, instead of -15 dB as in the FM-1 system. This reduces the adjacent DAB interference ratio to the FM signal from about -24 dB to about -31 to -34 dB, assuming the D/U at the edge of coverage is 6 dB. This predetection FM interference level should be sufficient to yield a post-detection signal to interference ratio of about 60 to 68 dB at the edge of coverage.

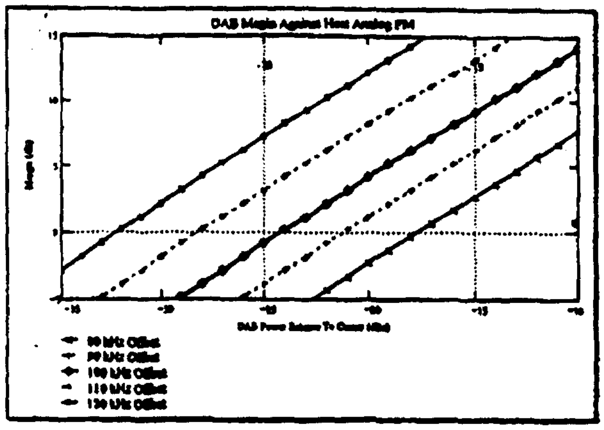

Figure 6. DAB Margin Against Host Analog FM.

The DAB margin against its host FM signal is plotted in Figure 6 as a function of the ratio of the DAB power to the FM power for different frequency offsets. The frequency offset is defined as the difference between the FM carrier (center) frequency and the closest edge of an ideal rectangular DAB spectrum. The DAB margin assumes a minimum of 5.2 dB Eb/No is required for the biorthogonal waveforms used in the FM-1 system with R=1/2, K=7 convolution coding. The FM host signal was generated with pseudo processed stereo music without SCAs. Figure 6 shows that a 90 kHz offset requires a relative DAB power of -22 dB to result in 0 dB margin. This margin increases to about 2.5 dB for a 100 kHz offset. It has already been stated that the "outer edge" of the DAB signal be limited to 200 kHz away from the FM carrier (center) frequency to prevent the second adjacent interference problem. This bounds the DAB bandwidth to about 100 kHz on either side of the FM spectrum.

The plot in Figure 7 shows the required first adjacent D/U vs. DAB power for several frequency offsets. This D/U requirement allows DAB to function with 0 margin. This graph illustrates that the required D/U is substantially above the 6 dB required for the analog FM signal. With a relative DAB power of -22 dB at 100 kHz offset, the required D/U is about 28 dB. With no solution to this problem, this could be considered a fatal flaw. Fortunately, a reasonable solution has been found, which has become incorporated as a component of the improved FM DAB design.

The solution to the first adjacent interference problem is to place redundant DAB signals on either side of the carrier. Although the potential bandwidth capacity is halved, interference problems are substantially reduced. A survey of existing U.S. radio allocations shows that it is very unlikely that both upper and lower adjacent channel interferers are present at their maximum levels simultaneously. At least one of the adjacent channel interferers must satisfy a D/U of about -28 dB. When both interferers satisfy this requirement, then a receiver has the option to dynamically select the DAB sideband with the least estimated bit errors. This frequency diversity is especially useful when multipath interference or spectral notches affect one sideband or the other.

Table 1 summarizes the goals for DAB coverage as a function of the estimated Eb/No for digital transmission, effective noise temperature (rural vs. urban), and Class of station (B or C).

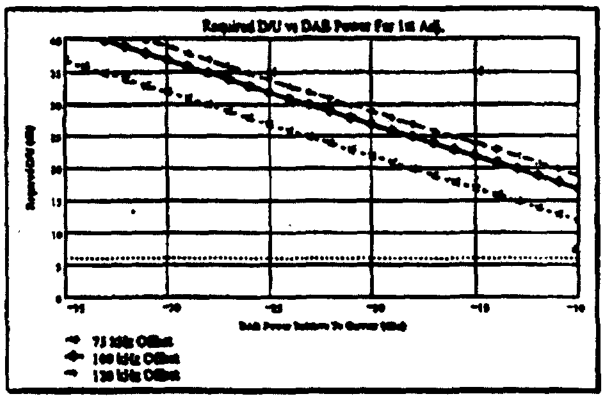

Figure 7. Required First Adjacent D/U Vs DAB Power.

III. WAVEFORM AND SIGNALING ANALYSIS

The FM-1 system employed a set of 48 biorthogonally-modulated spread spectrum waveforms. These waveforms were not the usual binary sequences of chips common to direct-sequence spread-spectrum. Instead, these waveforms consisted of processed sequences of pseudorandom numbers sampled at a rate of 1.536 MHz. These sequences were first generated with a pseudo-random number generator, then filtered to yield a spectrum with 2 DAB passbands, such as shown in Figure 2. The waveforms were made perfectly orthogonal through a process described in a pending patent application [2]. Each of the 48 processed waveforms are modulated with binary data at a rate of 8,000 symbols (bits) per second to yield an aggregate throughput of 384 kbps before FEC coding. In addition to the 48 information bearing waveforms, one more waveform is used for equalization and control.

After analysis of the FM-1 waveforms, it was determined that their autocorrelation and crosscorrelation characteristics were not the most desirable. These properties are illustrated in the normalized autocorrelation and crosscorrelation plots of the FM-1 waveforms in Figures 8 and 9, respectively, which were reproduced directly from the patent application [2]. Although the noise-like waveforms are perfectly orthogonal when the system is perfectly synchronized (notice the crosscorrelation at sample 192, which is perfectly synchronized) and no multipath is present, the crosscorrelation values are unacceptably high even with slight time offsets. Furthermore the high autocorrelation sidelobes resulting from the dual-passband filtering degrades acquisition performance, especially in the presence of multipath interference. Therefore, an equalizer was

Table 1. DAB Coverage Goals

E_b/N_0	T (K)	dBW	dBu	Class B Coverage Diameter (mi.)	Class C Coverage Diameter (mi.)	Comments
5	10,000	-107.5	37.6	67.1	100.1	Rural Home Coverage
5	100,000	-97.5	47.6	49.0	77.5	Urban Home Coverage
15	10,000	-97.5	47.6	49.0	77.5	Rural Mobile Coverage
15	100,000	-87.5	57.6	36.9	60.0	Urban Mobile Coverage

required to mitigate the effects of multipath. The still less-than-robust performance of FM-1 with the equalizer indicated that the equalizer did not adapt sufficiently fast to the changing multipath conditions. Consequently, the recommendation was made to replace the noise-like waveforms with another set of waveforms which is more robust in the presence of multipath.

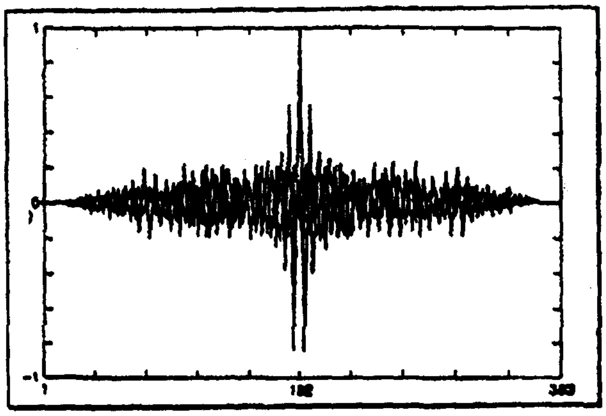

Figure 8. Autocorrelation of Several DAB (FM-1) Waveforms.

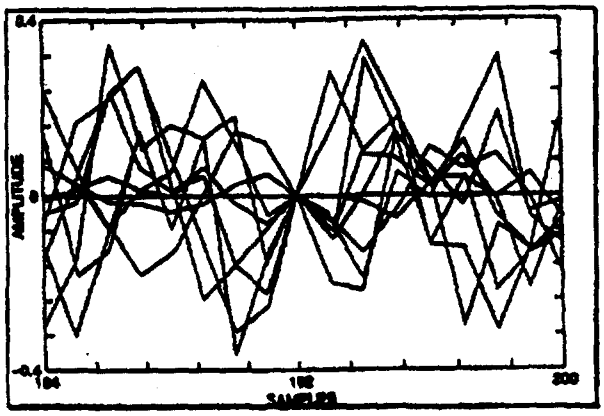

Figure 9. Crosscorrelation of Several DAB (FM-1) Waveforms.

<u>Alternate Spread Spectrum Signaling</u>

Analysis of the use of Gold codes for the spread spectrum waveforms showed significant promise. Although the Gold codes are not perfectly orthogonal with perfect synchronization, their autocorrelation and crosscorrelation properties are bounded. Using these bounds, one can construct a signaling system consisting of N multiple spread spectrum carriers where each carrier is M-ary modulated using nearly-orthogonal Gold code sequences. Therefore a total of M times N nearly-orthogonal Gold code sequences are needed. For example, it is possible to construct a signaling system consisting of 32 simultaneous 32-ary biorthogonal carriers, each operating at a chip rate of 75.6 kcps (raised cosine filtered to constrain within 100 kHz bandwidth) to yield a aggregate throughput of 192 kbps before FEC coding. This signaling system requires 1024 Gold codes with corresponding correlators in the receivers. This spread spectrum signaling is replicated on either side of the host FM spectrum as previously described to mitigate the effects associated with the first adjacent interference.

It is assumed here that the audio compression algorithm requires an information throughput of 96 kbps. Rate 1/2 coding will require a channel bit rate of 192 kbps which is replicated on each side of the FM host signal spectrum for diversity advantages.

The Gold codes offer improved performance over the noise-like waveforms in FM-1 because of their improved autocorrelation properties and bounded crosscorrelation properties for imperfect synchronization. The resulting system would yield superior performance in the presence of multipath fading. Although an equalizer may not be required, a rake receiver architecture is recommended to further enhance performance in the presence of multipath. The independent audit final report [1] quantifies the performance bounds discussed here.

Sample plots of the normalized autocorrelation and crosscorrelation properties of length 127 Gold Codes are presented in Figures 10 and 11, respectively. Crosscorrelation properties of Gold codes of various lengths are presented in Figure 12. The Eb/No requirements for biorthogonal signaling is plotted in Figure 13. An example of a Rake receiver structure for implementation of the M-ary biorthogonal signaling is shown in Figure 14. <u>The combined information in this section supports the viability of biorthogonal signaling using Gold Codes for the DAB application.</u>

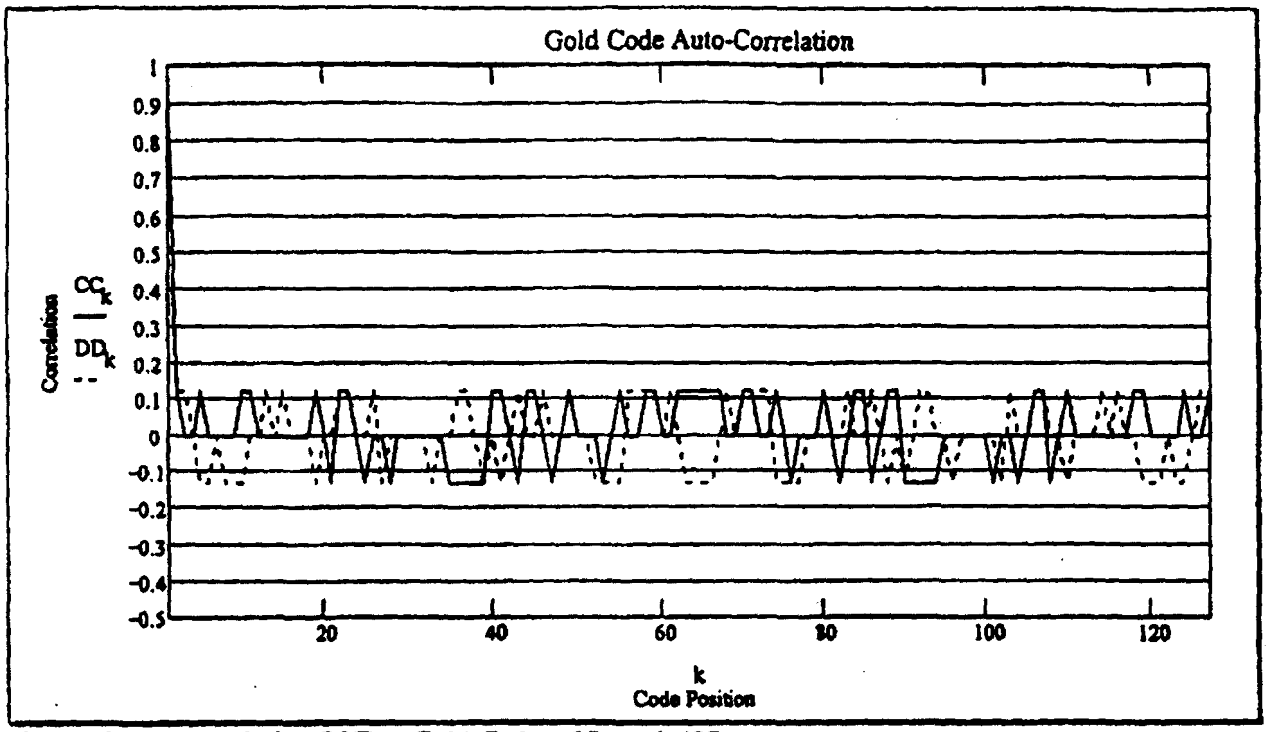

Figure 10. Autocorrelation Of Two Gold Codes of Length 127.

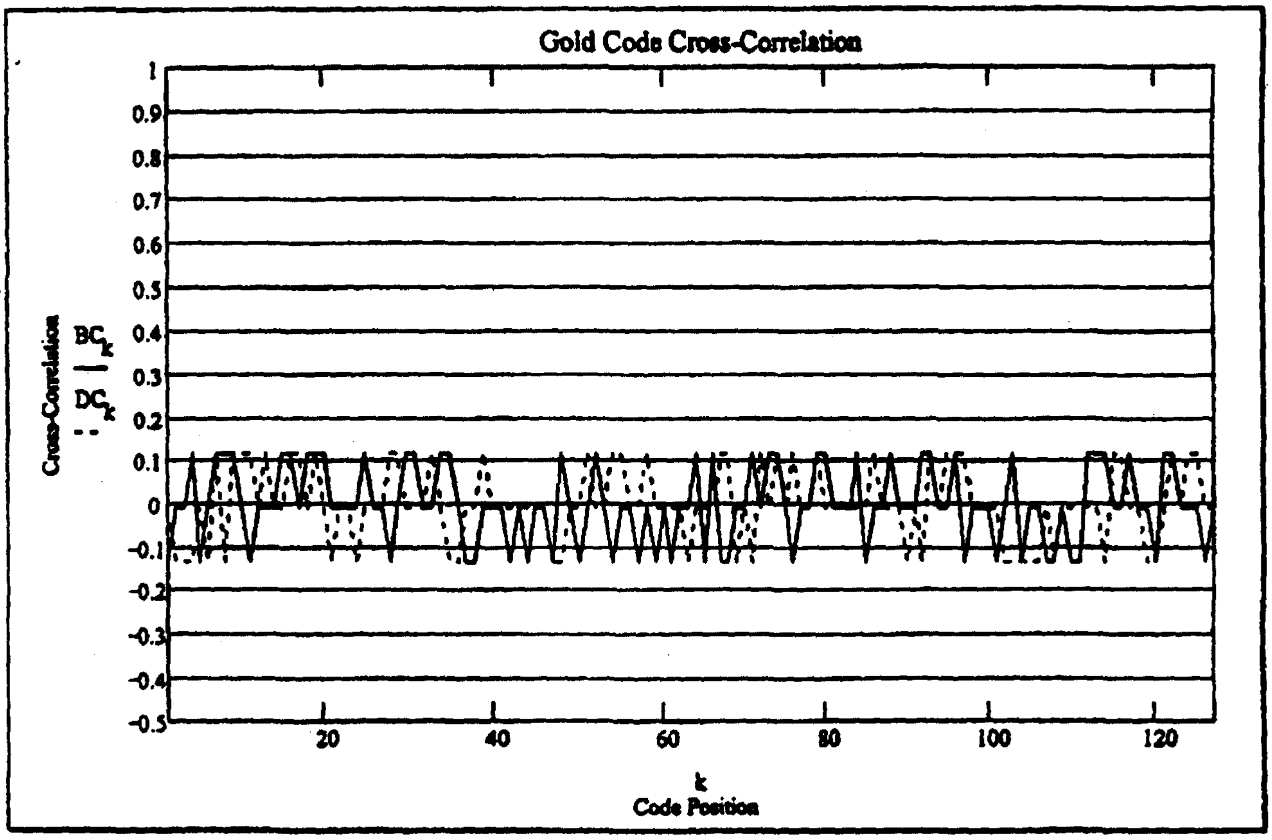

Figure 11. Cross-Correlation Of Two Sets of Gold Codes of Length 127.

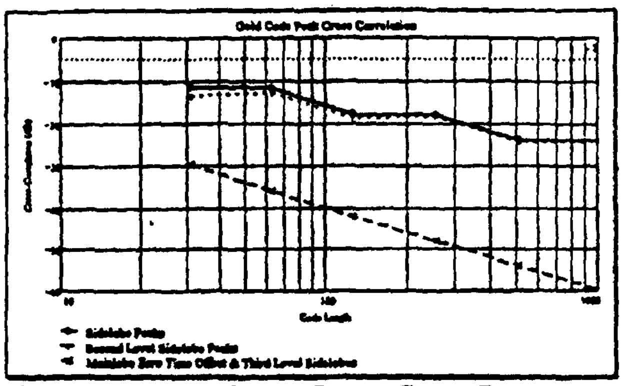

Figure 12. Gold Code Cross-Correlation Properties.

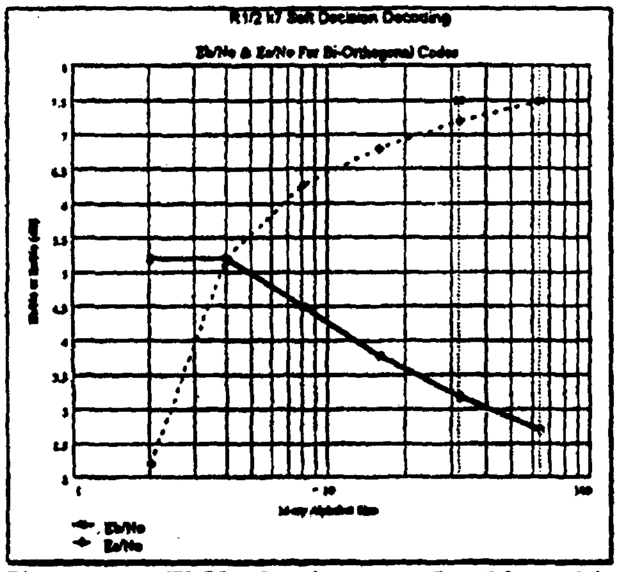

Figure 13. Eb/No Requirements For M-ary Bi-Orthogonal

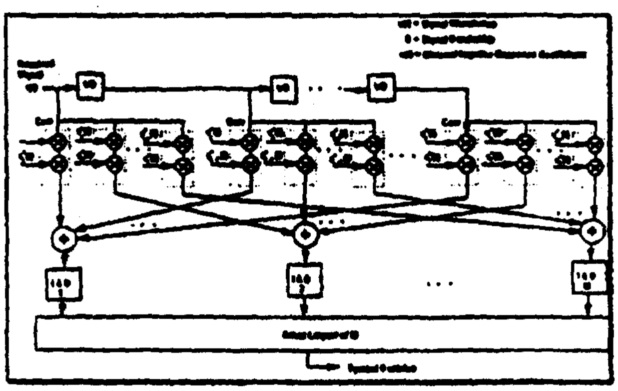

Figure 14. Rake Receiver Structure For M-ary Bi-Orthogonal Signaling.

<u>Alternate OFDM Signaling</u>

Orthogonal Frequency Division Multiplex modulation of redundant upper and lower sidebands may facilitate the exploitation of the FM signal characteristics by limiting the FM interference to a fraction of the subcarriers. An example of an OFDM spectrum using MPSK DAB subcarriers is shown in Figure 15. For instance, knowledge of the location of the instantaneous FM frequency over a particular symbol period can aid an FEC decoder with erasures. Also, signal processing techniques exist for suppressing the FM signal such that a data signal buried beneath it can be detected. Such techniques are presently being analyzed and simulated.

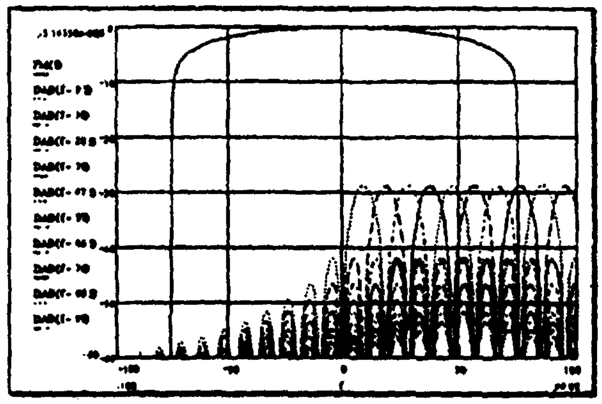

Figure 15. Example of OFDM MPSK DAB Carriers Beneath and Adjacent to the Analog FM Signal Spectrum.

IV. BLEND WITH TIME DIVERSITY

Perhaps the most effective method for dealing with the nonstationary mobile radio channel is to provide time diversity between two independent transmissions of the same audio source. Both AM and FM IBOC DAB concepts inherently provide this ability by delaying the analog transmission by a fixed time offset relative to the decoded DAB audio transmission. When the DAB transmission is blocked (or corrupted for any reason) for short time, then the outage at the DAB decoder is heard after the diversity delay. This diversity delay is incurred at the receiver and is comprised of deinterleaving and FEC decoding delay, audio decoding delay, and any additional delay for diversity improvement. The FEC decoder can be use to identify faulty audio frames and, therefore, the exact time of the DAB audio outage can be predicted. If the channel becomes unblocked after the diversity delay, then the analog signal can be demodulated such that its detected audio output can be blended in while blending out the faulty DAB segment. The listener may detect the temporary degradation in audio quality during the analog blend duration, but will not experience an outage or undesirable artifacts.

If the diversity delay is sufficiently large such that the DAB and analog outages are independent, then the probability of an outage after diversity is the square of the probability of outage without diversity. For instance, if the probability of an outage is 1.0%, then the probability of outage after diversity is 0.01%, which is a great improvement. The actual performance can be quantified with knowledge of the autocorrelation function of the channel outage due to severe impairment. This autocorrelation function is expressed as

$$R(\tau) = E\{x(t) \cdot x(t-\tau)\}$$

where $x(t)$ is defined as the stochastic process of the channel loss probability such that a "1" is assigned when the channel is lost and a "0" is assigned when the channel is clear, and τ is the diversity delay time offset. The probability of outage without diversity is $p = E\{x(t)\}$. The autocorrelation function is defined in this case such that it represents the probability of channel outage after diversity improvement as a function of time offset. An example autocorrelation function is shown in Figure 16; however, an actual autocorrelation function depends on distance from the station, terrain, propagation conditions etc. The figure shows that if the analog signal is not delayed relative to the DAB signal (zero time delay), then the outages are correlated and no benefit is gained from blending since the probability of outage remains the same as without diversity. If the delay is large, then events become uncorrelated and the probability approaches the square of the probability without diversity.

The blend feature also solves the problem of fast tuning time. Without blend a receiver would incur the diversity delay after tuning to a station before the listener hears the audio. The blend feature will demodulate the analog signal almost instantly allowing the listener to hear the selection before blending to DAB several seconds later.

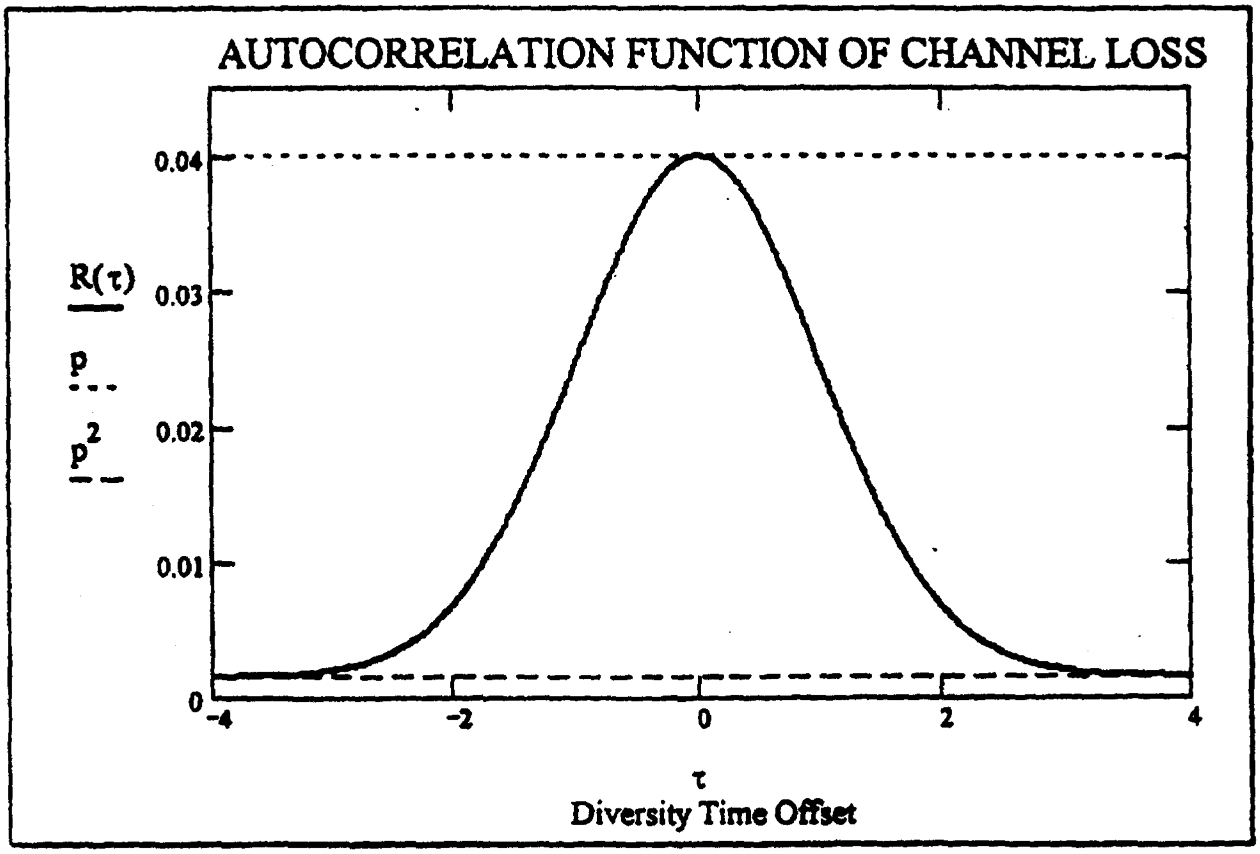

Figure 16. Example Autocorrelation Function of Channel Loss Due to Blockage or Severe Impairment (p=0.04).

DAB-only with Time Diversity

The IBOC designs permit evolution to an all-DAB format. Without the host analog signal present, the DAB will be transmitted within the primary spectral channel allocation, and not in the "wings". Adjacent channel interference issues are alleviated. The DAB power can be increased by as much as 30 dB, substantially increasing the DAB coverage area. The transmission format will include normal compressed audio plus a more compressed monophonic version of the same signal which is delayed by the diversity time offset. FEC with interleaving is applied to the normal compressed audio. The lower rate audio signal is used for blending during outages in place of the analog signal in the IBOC technique. Furthermore this lower rate audio signal employs FEC coding without interleaving. Therefore the all-DAB signal format facilitates fast tuning and exploits time and frequency diversity with the lower-rate redundant digital audio signal.

V. DATA UNDER FM

The IBOC DAB techniques discussed up to this point place their signals in the spectrum "wings" on either side of the FM analog signal (not directly under the FM signal, e.g. [3-8]). Although accurate detection of a DAB signal directly under the FM signal is difficult, the self-interference between the DAB and the FM signals of the host channel is somewhat controllable. The channel capacity in the "wings" using redundant sidebands is sufficient to support compressed audio with 1/2 rate FEC coding in addition to a very modest data rate (e.g. 2.4 kbps) for datacasting services. A need for more data capacity may be fulfilled through exploiting the spectrum directly under the FM signal.

Techniques have been developed which involve cancellation and/or notch filtering of the FM signal's instantaneous frequency to effectively suppress the FM carrier [3-8]. The DAB signal is extracted from below the FM carrier, although the extraction process distorts the DAB signal. It is assumed that the DAB signal is small (e.g. -30 dB) relative to the analog FM signal such that the DAB distortion to the post- existing FM stereo detection FM signal is acceptably negligible (e.g. -60 dB).

An FM extraction technique using dynamic predistortion at the transmitter with either OFDM or spread spectrum signals permits substantially more digital capacity (bps) with lower distortion to the analog signal than without the dynamic predistortion. Since both the analog FM signal and the DAB signal are known a priori at the transmitter, it is possible to predict the distortion to the DAB signal due to the DAB extraction process with a clear channel (no noise or fading). Specifically the distortion can be predicted with a DAB receiver located at the transmitter site. The distortion can be observed on each of the detected soft symbols of the DAB signal.

The DAB signal proposed in [3], as an example, consisted of OFDM MPSK carriers buried about 30 dB (total DAB power) beneath the analog FM signal. If the transmitter estimates the distortion in this manner, then adds the negative of this distortion (predistortion) to the composite signal to be transmitted, then a DAB receiver using the identical extraction algorithm as the local receiver will add the distortion which cancels with the predistortion. If the amount of predistortion is small compared to the DAB signal, then the additive distortion model is a reasonable approximation, and this was verified through OFDM simulation [3]. The additive model should be valid also for other waveforms such as the biorthogonal spread spectrum vector modulation. However this simulation assumed perfect synchronization and no noise or other channel impairments. The effects of noise and fading would degrade performance and should be evaluated before assuming conclusive results.

Since the transmitter processes the interfering FM signal seconds before transmitting it, the transmitter is able to predict the effects of its self-interference and deal with it. Several other techniques, in addition to the ones discussed here, have been conceived to exploit this cooperative interferer arrangement. It is expected that the use of DAB signal extraction techniques will result in a data channel capacity of 64 kbps.

VI. CONCLUSIONS

AM and FM IBOC DAB systems are being improved and upgraded by *USADR*. Detailed analysis and simulation results support the viability and robustness of these improved systems, of which demonstrations are anticipated in 1997.

The FM IBOC DAB system will provide virtual-CD quality stereo audio using redundant spectral sidebands to provide frequency diversity and immunity to first adjacent interference. Time diversity is provided through interleaving. A blend-to-analog feature, with time diversity in the order of seconds, permits virtually instant tuning time while filling DAB audio gaps due to blockages or severe impairments. This feature will dramatically improve coverage in areas characterized by intermittent blockages.

AM IBOC DAB will provide stereo audio quality similar to existing FM analog. AM IBOC DAB will exploit interleaving and blending-to-analog with time diversity features similar to FM IBOC DAB.

AM and FM DAB will offer superior DAB coverage through an option to transition, at a future date, to a reduced-quality analog simulcast or to digital only. This option offers an increase in DAB power with the addition of a supplemental DAB transmission consisting of a lower rate compressed audio signal for time diversity reception and nearly instant tuning. This last feature is extremely effective against intermittent blockages and severe impairments, providing performance impossible to otherwise achieve with only frequency diversity, interleaving and FEC.

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Reference 5

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Subject: DAR Subcommittee Draft Report on DAR System Performance

Dear Randy,

Although I was not in attendance at the most recent DAR Subcommittee meeting (held on Saturday, January 11, in Las Vegas, NV), I have been given a copy of a draft report which was distributed there entitled "Technical Evaluations of Digital Audio Radio Systems Performance". As stated in the introduction, this report is meant to provide an analysis of the laboratory and field test evaluations of the DAR systems recently concluded by CEMA (by and large, in conjunction with the NRSC) and contains, among other things, "...summary conclusions for adoption by the DAR Subcommittee."

Briefly stated, my purpose in writing you this letter is to inform you, and through you the DAR Subcommittee itself, of the NAB's objections to this report. Having participated heavily in the efforts of the NRSC's DAB Subcommittee myself for the past year, and having the collective experience of my colleagues here at NAB to rely upon, I feel qualified to state that this report is misleading, incomplete, and overall serves to trivialize the entire test process.

Furthermore, it is my understanding that this report was generated outside of the Subcommittee process, that is, rather than being the result of a deliberative effort amongst interested Subcommittee members and proponents, as had been discussed at numerous DAR Subcommittee meetings, it appeared as somewhat of a surprise, and was not attributed to any particular author or authors, for consideration by the Subcommittee which, at the very same meeting, proposed to suspend its activities at the conclusion of that meeting. Given the investment in time and effort by the many, many individuals associated with this process, it seems unjust to disenfranchise them for this, the culminating activity, and only serves to discredit the entire process.

This report is misleading because data are presented with little or no explanation, data which simply cannot be properly understood without at least some background information. For instance, in Section III.A. it is stated that "...the Eureka 147 DAB system (@224 kbit/s) is rated by expert observers to offer the best audio quality...", however no mention is made of the fact that the difference in performance between it and the next-best performing system was so small that statistically, they were judged to be the same. This fact was made quite clear in the lab data report, as can be seen in this excerpt:

> "...If [systems] differ by less than 0.17. this difference is not considered statistically significant since it could too easily be due to *chance*..." (emphasis added - from Lab Data Report, Appendix U. page 7)

Nor, continuing with this example, is any mention made of the fact that audio quality and bit rate (for 9 out of the 10 systems evaluated) are directly related - this reflects very poorly, I think, on a document which is supposed to be providing an evaluation of the results, when such an obvious and important fact as this is totally ignored.

This report is incomplete for a number of reasons, only some of which I will mention here. For the length of time that I was involved, and as I understand it, for most if not all of the time prior to that, this process was fraught with differing opinions and controversy over the specifics on approach, methodology, and even interpretation of results, at least in the case of the laboratory data. These issues are not addressed anywhere in the report, not even alluded to, and this is a grave omission. In this regard, the report is misleading as well as incomplete, by presenting the results as if there were no questions as to their validity.

Regarding the field test data specifically, what happened to the indoor data? No mention is made of it in either the released field test data report nor in the subject evaluation report. The Minutes of the NRSC DAB Subcommittee's Field Test Task Group clearly state that indoor measurements were completed on the Eureka 147 system (although only in multiple transmitter mode and not in both multiple and single transmitter modes, as had been agreed) but there is no data presented nor is the omission explained. Indoor data was also taken on the other two field-tested systems, yet it appears nowhere and is mentioned nowhere.

There are further problems regarding the completeness of the field test data. It was originally agreed by the Subcommittees, and this is reflected in the field test plan which they adopted, that to properly characterize the system performance in the field, four types of measurements would be made - "long path" (the only measurements presented in the reports), "short path", "point", and "inside". How can the subject report reach a definitive conclusion regarding system performance when only one out of four planned-for field test measurements were performed? Is this not an important point to mention in the summary report on this process?

Perhaps the most glaring omission involves an issue which is foremost in the minds of broadcasters, that being how the digital systems perform relative to existing analog techniques. This issue was very clearly stated in the Field Test Task Group "Objectives and Goals" statement and, in fact, is listed as the *first* objective,

> "To determine if the systems under test provide users with a signal quality and durability that is significantly greater than the AM and FM analog systems that presently exist in the United States."

This determination has not been made, one way or the other, in the evaluative report, and is not even mentioned, in spite of the fact that there is sufficient data collected to address this question, in particular for the field-tested systems. Without answering this, any report on the digital systems' performance is, quite frankly, totally useless as far as broadcasters in the United States are concerned, and for that matter would not seem to be of any help in establishing the future course which the U.S. should follow regarding DAB.

My next point, that this report trivializes the process, is based upon the premise that a test program requiring over two years worth of work, countless meetings and untold effort on the part of broadcasters, equipment manufacturers, consulting engineers, and the like, cannot possibly be analyzed and summarily judged in a mere eight pages as is done in the subject report (not counting the space used for system descriptions and introductory remarks). I don't know to what end the DAR Subcommittee intends to use this report, but I cannot believe that, in its present form, it would be useful for much of anything except to discredit the process, which is distressing because, like it or not, the NRSC and therefore the NAB have been and will continue to be linked to this work.

After having said all of this, I have a request - I would ask that, in your role as Chairman of the DAR Subcommittee, you reject this report outright, and either guide the Subcommittee towards an accurate, thorough, proper, and supportable analysis of the data which was collected, or, alternatively, do not pursue analysis of the test results further. Admittedly, this test process was a difficult one, and will no doubt always be controversial, but for one of the sponsoring organizations to endorse a report such as the one being considered only adds insult to injury.

Please feel free to contact me if you have any questions regarding this letter.

Sincerely,

David H. Layer

David H. Layer
Senior Engineer

cc: L. Claudy
B. Goldman
R. Justus
J. Marino
C. Morgan
M. Smith
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